CALIFORNIA DIVISION OF MINES AND GEOLOGY
FAULT EVALUATION REPORT FER-210
STEPHENS PASS FAULT AND FAULTS IN THE BUTTE VALLEY AREA, SISKIYOU COUNTY, CALIFORNIA

by

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INTRODUCTION

Potentially active faults in the Butte Valley study area of Siskiyou County that are evaluated in this Fault Evaluation Report (FER) include the historically active Stephens Pass fault and numerous, generally north-trending faults of Quaternary age in the Butte Valley area (Figure 1). These north-trending faults were previously unnamed. New names are proposed in this FER. The Butte Valley study area is located in portions of the Bartle, Bray, Dorris, Macdoel, and The Whaleback 15-minute quadrangles.

Faults in the Butte Valley study area are evaluated as part of a statewide effort to evaluate faults for recency of activity. Those faults determined to be sufficiently active (Holocene) and well-defined are zoned by the State Geologist as directed by the Alquist-Priolo Special Studies Zones Act of 1972 (Hart, 1988).

SUMMARY OF AVAILABLE DATA

The Butte Valley study area is located in both the western Modoc Plateau and eastern Cascade Range geomorphic provinces. The study area is located near the western and northwestern border of the Medicine Lake Highlands. Butte Valley is a structurally controlled closed drainage basin that is bounded on the west by the eastern Cascade Range, which is also referred to as the High Cascades (Wood, 1960). To the east and southeast, volcanic rocks typical of the Modoc Plateau are found with rocks of the High Cascades. The study area is characterized by generally east-west directed extensional tectonics which has resulted in north-trending normal faults typically expressed as block faulting.

Topography in the study area ranges from the flat playa surface of Butte Valley to the relatively rugged east-facing escarpment of the eastern High Cascades Range. The northern part of the study area is expressed by block-faulted volcanic plateaus that retain some constructional flow features. Topography in the southern part of the study area is more rugged and includes heavily forested mountains. Elevations in the study area range from 1100 meters to 2315 meters. Development is low, consisting of the small towns of Macdoel and Dorris in Butte Valley, the small settlement of Tennant, and McCloud near the southwestern part of the study area. The most significant activity in the study area is agricultural, including farming, grazing, and timber harvesting.

Rocks in the study area are predominately volcanic flow and pyroclastic rocks of late Tertiary to late Pleistocene age (Gay and Aune, 1958; Wagner and Saucedo, 1987; Williams, 1949; Wood, 1960). Quaternary deposits, which are generally sparse in most of the study area, include Pleistocene lacustrine and alluvial deposits in Butte Valley and fluvio-glacial deposits in the southwestern part of the study area. Deposits of late Pleistocene and Holocene alluvium occur in various isolated locations throughout the study area.

The available literature for the Butte Valley study area is limited. The west side of Butte Valley was mapped by Williams (1949) at a scale of 1:125,000. Faults mapped by Williams offset late Tertiary volcanic rocks of the High Cascades Series, but are not shown to extend into late Pleistocene to Holocene alluvial and lacustrine deposits of Butte Valley. However, one short fault offsets late Quaternary deposits in the Butte Creek drainage southeast of Horsethief Butte. Wood (1960) mapped the Butte Valley area from the Oregon border to about 8km south of Cedar Mtn. at a scale of 1:62,500. Faults mapped by Wood are similar to faults mapped by Williams in western Butte Valley, including the area southeast of Horsethief Butte. Only Wood will be evaluated in this FER due to the relatively small scale of Williams' map and the general similarity of the mapping. The study area south of the area mapped by Wood has only been mapped at a reconnaissance level and at a small scale (Gay and Aune, 1958; Wagner and Saucedo, 1987).

Aerial photographic interpretation by this writer of faults in the Butte Valley study area was accomplished using aerial photographs from the U.S. Department of Agriculture (DDC, 1955). Fault traces were plotted directly on the aerial photographs and then transferred to 15-minute quadrangle base maps using a Bausch and Lomb Zoom Transfer Scope.

Approximately four days were spent in the field in early August 1989 by this writer and G. Borchardt. Selected fault traces were verified and subtle features not observable on the aerial photographs were mapped in the field. Soil pits were excavated to provide preliminary descriptions of soil development on selected geomorphic surfaces. Results of aerial photographic interpretation and field observations by this writer are summarized on Figures 2a-2c.

None of the faults in the Butte Valley study area, with the exception of the Stephens Pass fault, have been named. It would be exceedingly difficult to discuss this large number of faults without some identification. Therefore, informal names are introduced in order to facilitate discussion. Principal faults that will be evaluated in this FER include the Cedar Mountain fault zone, Mahogany Mountain fault, Ikes Mtn. and Meiss Lake faults, Mt. Hebron fault zone, and the Stephens Pass fault (Figures 1, 2a - 2c). Additional faults evaluated include the Ash Creek fault zone and the Black Fox Mtn. fault (Figures 1, 2c).

CEDAR MTN. FAULT ZONE

The Cedar Mtn. fault zone is an extremely complex, 44km-long zone of north-trending normal faults (Figures 1, 2a and 2b). South of Cedar Mtn. the fault zone is about 5 km wide and consists of two principal branches, the East Cedar Mtn. and West Cedar Mtn. faults (Figure 2b). North of Cedar Mtn. the fault zone widens to about 11 km just south of Butte Valley. The numerous short, northwest-trending faults that occur in the playa of Butte Valley will be discussed as a separate section of the Cedar Mtn. fault zone (Figure 2a).

East Cedar Mtn. Fault

Literature Review

The East Cedar Mtn. fault was mapped by Wood (1960) as two normal faults with down to the east vertical displacement (Figures 2a and 2b). The main western strand offsets Cedar Mtn., a Plio-Pleistocene volcanic cone. Total vertical offset is not known, but scarp heights on Cedar Mtn. suggest a minimum cumulative displacement of about 60 meters. Wood mapped late Pleistocene Butte Valley Basalt offset or juxtaposed against Holocene alluvium in the northern part of Antelope Creek (locality 1, Figure 2b) and just west of Sheep Mtn. (locality 2, Figure 2a). Wood reported that the age of the Butte Valley Basalt is late Pleistocene and possibly early Holocene, based on field observations that this unit locally overlies Pleistocene(?) lacustrine deposits in Butte Valley.

Aerial Photographic Interpretation and Field Observations

Traces of the East Cedar Mtn. fault mapped by Wood were mostly verified by this writer, based on aerial photographic interpretation and brief field inspection (Figures 2a and 2b). Fault traces are moderately well to locally well-defined and are delineated by geomorphic features suggesting latest Pleistocene to Holocene displacement, such as sharp scarps with associated troughs or fissures, closed depressions, and ponded alluvium (localities 2, 3-5, Figures 2a, 2b) (see Conclusions section for discussion of the significance of fissures). Faults north and east of Sheep Mtn. form a more complex pattern than mapped by Wood, based on aerial photographic interpretation by this writer (Figure 2a). These short northwest-trending faults are delineated by scarps and tonal lineaments in young alluvium presumed to be Holocene, a vertically offset drainage, and closed depressions (localities 6-8, Figure 2a). Faults along the west flank of Sheep Mtn. are delineated by geomorphic features indicating a significant component of right-lateral strike-slip displacement (locality 9, Figure 2a).

It is uncertain what significance fault scarp morphology in resistant basalt has in relation to fault recency. However, a 2m-high fault scarp in unconsolidated gravel south of the Antelope Sink has a scarp-slope angle of about 20°, supporting an interpretation of latest Pleistocene to Holocene offset along the East Cedar Mtn. fault (locality 5, Figure 2b).

The offset gravel deposits south of Antelope Sink are probably equivalent in age to late Tioga outwash deposits of the eastern Sierra Nevada (11-13ka; Smith, 1979) (localities 5 and 10, Figure 2b). The gravels have a poorly developed A-C horizon and contain andesite clasts. The gravels overlie Butte Valley Basalt at this locality and were also found in the Antelope Creek drainage on the downthrown side of the East Cedar Mtn. fault (locality 11, Figure 2b). This indicates that offset along the East Cedar Mtn. fault has occurred since the deposition of these gravels.

Although previously not mapped, the area just north of Dry Creek Peak and Rainbow Mtn. (locality 12, Figure 2c) was glaciated during the Wisconsin. Classic alpine glacial features, such as U-shaped valleys, aretes, horns, and cirques are associated with moraines in this part of the Antelope Creek drainage. Much of the Dry Creek Peak area is underlain by andesitic rocks (Gay and Aune, 1958). The Antelope Creek drainage just to the north of Rainbow Mountain is U-shaped in cross section and contains lateral and recessional moraines (Figure 2b). Therefore, most of the Antelope Creek drainage area probably received outwash deposits from the glaciated Dry Creek Peak area. The presence of rounded andesite clasts found on both the upthrown and downthrown sides of the East Cedar Mtn. fault in the Antelope Sink is consistent with the observation that the Dry Creek Peak area was glaciated and that the source area for the faulted outwash gravels in the Antelope Creek drainage was Dry Creek Peak.

Slip rates for the Cedar Mtn. fault zone and other faults in the Butte Valley study area are not known. The 2m-high scarp in late Tioga outwash gravels indicates that a minimum late Pleistocene slip-rate of about 0.2mm/yr can be estimated for the East Cedar Mtn. fault. It is likely that a comparable slip rate exists for the West Cedar Mtn. fault, based on geomorphic expression that is similar to the East Cedar Mtn. fault.

West Cedar Mtn. Fault

Literature Review

The West Cedar Mtn. fault mapped by Wood (1960) is a north-trending normal fault characterized by down to the east displacement (Figure 2a and 2b). The West Cedar Mtn. fault splays into essentially three branches north of Cedar Mtn.. The principal trace of the West Cedar Mtn. fault offsets the western flank of Cedar Mtn. and late Pleistocene Butte Valley Basalt. The fault juxtaposes late Pleistocene to Holocene alluvium against basalt at locality 13 (Figure 2b). The westernmost trace of the West Cedar Mtn. fault offsets late Pleistocene to Holocene alluvium of Butte Valley according to Wood (locality 14, Figure 2a).

Aerial Photographic Interpretation and Field Observations

The West Cedar Mtn. fault mapped by Wood (1960) was generally verified by this writer, based on aerial photographic interpretation and field inspection, although differences in detail exist (Figures 2a and 2b). South of Cedar Mtn. the fault consists of a single principal trace delineated by a moderately well-defined east-facing scarp in Butte Valley Basalt. Closed depressions, ponded alluvium, unfilled fissures, and vertically offset drainages are associated with the east-facing scarp (Figures 2a and 2b) (refer to Conclusions section for discussion of fissures). North of Cedar Mtn. the fault branches into two traces with minor associated branches (Figures 2a and 2b). This interpretation differs slightly from Wood's mapping because the central trace of Wood was not verified. The fault in alluvium mapped by Wood at locality 14 (Figure 2a) was verified by this writer, based on aerial photographic interpretation. This fault is delineated by a southwest-facing scarp in alluvium, a closed depression, and ponded alluvium (Figure 2a).

Southeast of Macdoel traces of the West Cedar Mtn. fault are delineated by well-defined east-facing scarps in Butte Valley Basalt (Figure 2a). These scarps are associated with prominent unfilled fissures (locality 15) and ponded alluvium (Figure 2a). A small cinder cone is vertically offset at locality 16.

Faults in Butte Valley

Literature Review

Northwest of Sheep Mtn. the Cedar Mtn. fault zone splays into an extremely complex, approximately 11 km wide zone of northwest-trending normal faults (Figure 2a). Wood (1960) did not map any of the northwest-trending faults in Butte Valley, although he did extend the Mahogany Mountain fault across the playa surface east of what is considered to be the Cedar Mtn. fault zone (refer to Mahogany Mountain discussion for evaluation of this fault) (Figure 2a). Wood did map a northwest-trending fault along both sides of Indian Point that projects southeast to the Cedar Mtn. fault zone (Figure 2a). These faults offset bedrock, and the southwestern fault is shown to offset latest Pleistocene to Holocene alluvium.

Aerial Photographic Interpretation and Field Observations

The broad fault zone in Butte Valley is delineated by moderately defined to locally well-defined tonal lineaments and subtle scarps in latest Pleistocene to Holocene lacustrine deposits (Figure 2a). Closed depressions, ponded alluvium, and a vertically offset minor drainage are associated with these tonal lineaments and scarps, indicating Holocene displacement (localities 8, 17-19, Figure 2a).

Many of the features identified on Figure 2a are linear concentrations of vegetation on the playa surface. Some of the scarps interpreted from air photos may in fact be vegetation lineaments. It was not possible to field check all of the subtle scarps identified, but where possible those thought to be vegetation lineaments are identified on Figure 2a (i.e. locality 20). Other scarps interpreted from air photos were verified during field inspection (i.e. locality 21). Many of the northwest-trending vegetation contrasts are comprised of eolian mounds upon which vegetation such as sage grows much more vigorously than the surrounding vegetation. It is probable that fissuring and minor vertical displacement associated with earthquakes occurred, disrupting the playa surface. These fissures became traps for eolian deposition, allowing a more hardy stand of vegetation to grow. Also, it is possible that ground water barriers are associated with some of the better-defined lineaments.

It is not likely that most of the features in Butte Valley formed by fluvial or lacustrine processes, based on the associated closed depressions, ponded alluvium, and the general northwest trend that parallels bedrock faults to the south and east (Figure 2a). One can argue that some of these features formed by lateral spreading due to liquefaction. However, lateral spreading features typically form sinuous graben, which generally were not observed. Although lateral spreading cannot be ruled out everywhere, the scarps and tonal lineaments in Butte Valley closely mimic the geomorphic expression of the Cedar Mtn. fault zone to the south. If one assumes that the formation of fissures has been the most recent episode of deformation along strands of the Cedar Mtn. fault zone, then this style of deformation is consistent with features observed in the Butte Valley playa.

A soil pit excavated in the playa surface of Butte Valley indicated a moderate amount of soil development, including a Bt horizon (locality 22, Figure 2a). Mounds that have accumulated around vegetation at the surface also have a weakly developed B soil horizon, suggesting that the rate of clay accumulation is relatively high in this region. The age of the Butte Valley playa surface is probably latest Pleistocene (equivalent to the late Tioga glacial stage of the eastern Sierra Nevada) to early Holocene, assuming that the late Quaternary glacial-pluvial history is equivalent to Pleistocene Lake Lahonton (Benson, 1978; Broecker and Kaufman, 1965; Broecker and Orr, 1958).

The northwest-trending scarp along the east side of Indian Point generally lacks geomorphic evidence of latest Pleistocene to Holocene displacement except for a short, subtle scarp in alluvium and a linear band of non-vegetated talus (Figure 2a). The lower two-thirds of this escarpment is covered with talus that has considerable vegetation. However, a linear band of this talus has no vegetation cover, indicating a steeper slope angle and possible recent displacement (Figure 2a).

MAHOGANY MOUNTAIN FAULT ZONE

Literature Review

The Mahogany Mountain fault zone is a northwest-trending zone of normal faults generally with down to the southwest vertical displacement (Figure 2a). Faults mapped by Wood (1960) are located along the northeast side of Butte Valley and offset Plio-Pleistocene volcanic rocks of the High Cascades series. Maximum vertical displacement is not known, but scarps in late Tertiary bedrock suggest a minimum cumulative displacement of about 500 meters. Most of the faults mapped by Wood are concealed by Holocene talus, but his western trace is shown to offset Holocene alluvium south of Dorris and Holocene talus along the western flank of Mahogany Mountain (localities 23 and 24, Figure 2a).

Aerial Photographic Interpretation and Field Observations

Only the western branch of the Mahogany Mountain fault zone was verified by this writer as having evidence of latest Pleistocene to Holocene offset (Figure 2a). The western branch fault is delineated by a moderately well-defined bedrock escarpment. Colluvium may be offset along this fault southeast of Dorris (locality 25, Figure 2a). The southern extent of the fault is delineated by a sharp bedrock escarpment and an associated linear band of non-vegetated talus. To the north the fault extends across Butte Valley playa and is delineated by a moderately well-defined, approximately 2 meter-high scarp in latest Pleistocene to Holocene alluvium (locality 23, Figure 2a). Scarp profile measurements were not made because this scarp is located in a plowed field and has been extensively altered.

The fault along the eastern side of Pleasant Valley is delineated by a bedrock escarpment similar to the escarpment along the east side of Mahogany Mountain (Figure 2a). Although specific geomorphic evidence of latest Pleistocene to Holocene displacement was not observed, the scarp has a linear band of talus similar to that observed along the southern extent of the fault (Figure 2a).

IKES MTN. FAULT

Literature Review

The Ikes Mtn. fault mapped by Wood (1960) is a north-trending normal fault that forms the western side of Butte Valley (Figures 1, 2a). The fault offsets Plio-Pleistocene volcanic rocks a minimum of about 240 meters (down to the east), based on the maximum height of the east-facing escarpment. The fault locally juxtaposes volcanic bedrock against Holocene alluvium (Wood, 1960).

Aerial Photographic Interpretation and Field Observations

The Ikes Mtn. fault mapped by Wood was not verified as a late Pleistocene to Holocene active fault by this writer, based on air photo interpretation. Geomorphic features indicative of recent faulting were not observed and an alluvial fan at locality 26 is not offset (Figure 2a). Parts of the Ikes Mtn. fault are modified by large landslides.

MEISS LAKE FAULT

The Meiss Lake fault is a previously unmapped north-trending fault located north of Meiss Lake (Figure 2a). The fault offsets Holocene alluvium and truncates a Holocene (modern ?) shoreline of Meiss Lake. The fault in bedrock east of Sams Neck is moderately well-defined and is delineated by a linear trough, beheaded and detoed drainages, and a right-laterally deflected drainage, suggesting a component of strike-slip displacement (Figure 2a). It could be argued that the fault in bedrock is erosional, but the moderately well-defined scarp in alluvium south of this bedrock prominence supports

Holocene activity. It is possible that the scarp in alluvium is a shoreline, but the scarp faces the wrong direction and it aligns with the geomorphic features in bedrock to the north.

A sharp tonal lineament in Holocene alluvium and a possible scarp (modified by grading) were observed south of Meiss Lake (Figure 2a). It is possible that these north-trending geomorphic features are the southern extent of the Meiss Lake fault.

MT. HEBRON FAULT ZONE

Literature Review

The Mt. Hebron fault zone consists of north to northwest-trending normal faults that form a zone up to 7 km wide (Figures 2a and 2b). Faults mapped by Wood (1960) offset Plio-Pleistocene volcanic rocks and locally offset late Pleistocene alluvium or juxtapose Holocene alluvium against bedrock or older alluvium (Figures 2a and 2b).

The fault zone mapped by Wood is loosely comprised of three principal strands. The eastern strand, which may be more characteristic of the Cedar Mtn. fault zone, offsets Plio-Pleistocene volcanic rocks along the east side of Orr Mountain and locally juxtaposes bedrock against Holocene alluvium (Figure 2b). The central strand mapped by Wood is located along the eastern flank of Mt. Hebron and locally juxtaposes Holocene alluvium against bedrock south of Orr Lake. The northern end of the fault is concealed by Holocene alluvium.

The western strand of the Mt. Hebron fault zone consists of at least three discontinuous traces that trend more to the northwest. The westernmost trace offsets Pleistocene fluvio-glacial deposits (equivalent to Tahoe glacial stage of eastern Sierra Nevada?) mapped by Wood in Butte Creek drainage (Figure 2b). The central trace was inferred to offset Holocene alluvium southeast of Prather Ranch as mapped by Wood (locality 27, Figure 2a).

Aerial Photographic Interpretation and Field Observations

The eastern strand of the Mt. Hebron fault zone can be extended farther south of the area mapped by Wood, based on aerial photographic interpretation by this writer (Figure 2b). This fault is delineated by a moderately well-defined scarp in Plio-Pleistocene volcanic rock. The east-facing scarp is similar in geomorphic expression to faults in the Cedar Mtn. fault zone. The age of the bedrock is only an assumption because the mapping of Wood, which shows these late Tertiary rocks juxtaposed against late Pleistocene Butte Valley Basalt, ended in sec 27, T44N, R1W (Figure 2b). There was not sufficient time in the field to verify whether the east-facing scarp was in late Pleistocene Butte Valley Basalt or late Tertiary High Cascade series rocks. A Holocene alluvial fan in the Butte Creek drainage is not offset along this strand of the Mt. Hebron fault zone, although Butte Creek has not re-established its gradient on the uplifted block west of the fault (locality 28, Figure 2b).

The central strand of the Mt. Hebron fault zone mapped by Wood was generally verified with respect to location by this writer, although differences in detail exist. However, the fault is only moderately defined at best. A poorly defined, degraded scarp in Pleistocene alluvium could be mapped farther south than shown by Wood (locality 29, Figure 2b).

The western strand of the Mt. Hebron fault zone mapped by Wood was only locally verified with respect to location by this writer based on air photo interpretation. The offset Holocene alluvium inferred by Wood at locality 27 (Figure 2a) was not verified. The western strand consists of poorly to moderately defined, discontinuous traces. Evidence of late Quaternary displacement along this western strand is suggested by a possible scarp in a late Pleistocene(?) terrace at locality 30 (Figure 2b). However, evidence against Holocene activity is more convincing and includes an unfaulted terrace at locality 31, lack of evidence of offset minor drainages, including an incised minor drainage through a scarp in basalt (localities 32 and 33), and an absence of offset young alluvium (Figure 2b). Much of the northern end of the western strand is concealed by landslide deposits.

STEPHENS PASS FAULT

Literature Review

The Stephens Pass fault (Figure 2c) was not recognized until the occurrence of the August 1, 1978 Stephens Pass earthquake (Bennett and others, 1979). The initial shock of M 4.6 occurred August 1 and was followed by 6 events of M 3.5 to 4.5 within the next 90 minutes. Focal depths for this earthquake swarm were relatively shallow, usually less than 4 km. Focal plane solutions indicated east-west extension along a north-striking fault that dips 35°-45° east.

Surface fault rupture associated with this earthquake swarm extended for approximately 2 km along a pre-existing east-facing scarp in latest Pleistocene to Holocene basalt (Bennett and others, 1979) (Figure 2c). Surface fault rupture was expressed in a complex zone up to 75 meters wide which consisted of fractures, scarps, and graben. Extensional openings along fractures were as great as 50 cm, although the average extensional opening was 15 cm. Scarps along the margins of graben associated with the 1978 E/Q range in height from 5 to 30 cm. The center of some graben subsided as much as 1 meter.

It is somewhat anomalous that such a small magnitude earthquake would be associated with such large surface rupture. It was proposed that causes other than fault rupture produced this surface displacement. One popular hypothesis was that a lava tube collapsed below the surface, forming the troughs and graben observed after the earthquake swarm. However, pre-existing shallow troughs or graben are associated with the east-facing scarp in basalt, indicating prior surface rupture. It seems improbable that the collapse of a lava tube would be of a recurring nature. Also, the pre-existing geomorphology and the surface deformation associated with the 1978 earthquake swarm are consistent with many north-trending faults to the north.

Aerial Photographic Interpretation and Field Observations

The Stephens Pass fault is generally only moderately defined by an east-facing scarp in volcanic bedrock, based on aerial photographic interpretation (Figure 2c). The fault mapped by Bennett and others and plotted on a small-scale base map was mostly verified by this writer, although slight differences in detail exist primarily in the southern part of the zone (Figure 2c). It should be mentioned that most of the fault is located in a heavily forested area, and interpretation of aerial photographs is limited. Subtle troughs and graben associated with the east-facing scarp in basalt are moderately to well-defined, based on field observations. A well-defined 1m-high scarp in alluvium of probable Holocene age was observed just south of Stephens Pass Road (locality 36, Figure 2c). This area had been logged prior to the August 1989 field inspection, yet the scarp could be followed to the south for about 1 km. Subtle troughs near the top of an east-facing scarp in basalt are similar to the troughs and graben associated with the segment of the fault that ruptured in 1978 (locality 37, Figure 2c). Surface fault rupture associated with the 1978 Stephens Pass earthquake was remarkably well-preserved and easily observed during field inspections in June and August 1989.

Several short north and northeast-trending faults were mapped in the Horse Peak area, about 2km north of the northern extent of the Stephens Pass fault (Figure 2c). These unnamed faults are characterized by west to northwest-facing (uphill-facing) scarps in Quaternary volcanic bedrock. Two closed depressions (or ponded alluvium) are associated with the easternmost fault, but generally these faults are not as well-defined as the Cedar Mtn. fault zone to the north. Although these faults appear to be better defined than the Stephens Pass fault, they do not seem to be characterized by the young troughs and fissures associated with the Stephens Pass fault, based only on air photo interpretation. However, these north and northeast-trending faults are more apparent on the air photos because the area had been clear-cut prior to the aerial photography.

ASH CREEK FAULT ZONE

The Ash Creek fault zone has not been previously mapped, except on a reconnaissance basis by Gay and Aune (1958) (Figure 1 and Figure 2c)(mapping by Gay and Aune not shown on Figure 2c). The Ash Creek fault zone mapped by this writer consists of two subparallel, generally north-trending faults that offset Quaternary volcanic rocks. Faults mapped by Gay and Aune locally offset alluvium, but this offset was not verified by this writer. The fault at locality 34 is poorly defined and is concealed by late Pleistocene to Holocene alluvium (Figure 2c).

The eastern strand of the Ash Creek fault zone is moderately well-defined and offsets basalt that is probably older than late Pleistocene, based on the presence of a B-soil horizon. The presence of this soil horizon on the scarp face suggests a lack of recency (locality 35, Figure 2c).

BLACK FOX MTN. FAULT ZONE

The Black Fox Mtn. fault zone consists of several generally north-trending normal faults that form a zone up to 3½ km wide (Figure 2c). This previously unmapped fault zone is delineated by both east and west-facing scarps in Quaternary and late Tertiary volcanic rocks mapped by Gay and Aune (1958). Strands of the Black Fox Mtn. fault zone are generally poorly defined and lack geomorphic evidence of latest Pleistocene to Holocene offset (Figure 2c).

SEISMICITY

Seismicity in the Butte Valley study area is very sparse (CIT, 1985). The most notable activity is the August 1978 Stephens Pass earthquake swarm. To the north a cluster of about three events of M 3 are located just west of Tennant along the southern projection of the West Cedar Mtn. fault zone.

CONCLUSIONS

Faults in the Butte Valley study area generally offset late Quaternary volcanic rocks. The faults are predominately normal and are delineated by scarps in these resistant volcanic rocks. However, it is difficult to estimate the recency of these faults based on fault scarp morphology because the rate of degradation is not known and is undoubtedly much higher than for scarps in unconsolidated alluvium.

SIGNIFICANCE OF LINEAR FISSURES

Linear fissures associated with well-defined fault scarps were observed along many of the north-trending faults of the Cedar Mtn. fault zone (indicated by an F on Figures 2a and 2b). These fissures usually are found along the upper 1/3 of the scarp (generally near or at the top), can be wider than 10 meters, as deep as 25 meters, and extend for at least 1 km or more. The fissures are associated with many different sized scarps, from large scarps greater than 20 meters high to scarps less than 2 meters high. The fissures that were field checked generally are unfilled or contain very young deposits. Eolian deposits excavated in a small fissure at locality 3 (Figure 2a) had no soil development, indicating that the fissure had formed during Holocene time.

These fissures may be a key to evaluating the youthfulness of scarps in resistant volcanic rock. Linear fissures that are unfilled are believed to have formed less than 10 ka. If a fissure had formed prior to the end of the Pleistocene, it seems likely that eolian deposits would have accumulated in the fissure, perhaps burying some of the smaller fissures. The tectonic style in the Modoc Plateau seems to be pure extension. It is possible that a thin, brittle layer at the surface such as the Butte Valley Basalt may respond to tensional strain by forming fissures, both along pre-existing fault scarps and on the flat volcanic plateaus away from scarps. It is perhaps significant that the Stephens Pass fault is characterized by pre-existing shallow graben or troughs, in addition to the generally east-facing scarp. Surface fault rupture associated with the

1978 Stephens Pass earthquake genrally broke along these pre-existing graben and troughs. These geomorphic features are characteristic of extensional tectonics and may be similar to the fissures observed in young basalt to the north along the Cedar Mountain fault zone.

It could be argued that fissures near the top of a fault scarp were formed by toppling. This may be a plausible explanation, but it seems unreasonable that fissures of relatively uniform width caused by toppling would extend along a scarp for greater than 1 km. Alternatively, the fissures located near the tops of scarps may have formed in response to monoclinal warping of the brittle volcanic flows. The fissures may have formed near the convex part of the warp.

CEDAR MTN. FAULT ZONE

The Cedar Mtn. fault zone is an extremely complex, northwest-trending zone of generally down to the east normal faults that consist of the East and West Cedar Mtn. faults and faults in Butte Valley (Figures 1, 2a, and 2b).

The East and West Cedar Mtn. faults mapped by Wood (1960) (Figures 2a and 2b) were generally verified by this writer, based on aerial photographic interpretation and field inspection. Traces of the East and West Cedar Mtn. faults are moderately well to well-defined and are delineated by geomorphic features indicative of latest Pleistocene to Holocene offset, such as unfilled fissures associated with sharp scarps in basalt, scarps in latest Pleistocene to Holocene alluvium, closed depressions, and ponded alluvium (localities 2-8, Figures 2a and 2b). A preliminary slip-rate estimate of 0.2mm/yr was calculated for the East Cedar Mtn. fault, based on a 2m-high scarp in outwash gravels assumed to be equivalent in age to the late Tioga glacial stage of the eastern Sierra Nevada.

Faults in Butte Valley form an 11-km-wide northwest trending zone of discontinuous tonal lineaments and low scarps in latest Pleistocene to Holocene lacustrine deposits (Figure 2a). These faults were not mapped by Wood (1960). The trend of faults in Butte Valley is consistent with the trend of faults in bedrock to the southeast, and although it is possible that some of these tonal lineaments may have formed due to liquefaction caused by earthquakes, it is probable that most are tectonic in origin. If the assumption that the tectonic style is mostly extension is correct, then a broad zone of discontinuous fissures and small scarps in alluvium is consistent with observed displacements in bedrock to the southeast and historic fault rupture along the Stephens Pass fault.

MAHOGANY MOUNTAIN FAULT ZONE

The Mahogany Mountain fault zone consists of northwest-trending normal faults along the northeast side of Butte Valley mapped by Wood (1960) (Figure 2a). The westernmost strand of the fault mapped by Wood (1960) offsets latest Pleistocene to Holocene lacustrine deposits at locality 23 and Holocene alluvium at locality 24 (Figure 2a). The fault at locality 23 is delineated by a moderately well-defined (modified by grading) approximately 2 meter-high scarp. The fault in alluvium mapped by Wood at locality 24 was not verified by this writer, but additional evidence of latest Pleistocene to Holocene offset along the western strand was observed at locality 25 (Figure 2a).

The western strand of the Mahogany Mountain fault northwest of Butte Valley is only moderately defined by a bedrock escarpment. Geomorphic evidence of recent faulting is generally absent except for a linear band of talus that may indicate a steeper scarp-slope angle in talus and thus recent displacement (Figure 2a).

IKES MTN. FAULT

The Ikes Mtn. fault mapped by Wood (1960) is a north-trending normal fault with down to the east normal displacement (Figure 2a). This fault is not well-defined and is not delineated by geomorphic features indicative of latest Pleistocene to Holocene displacement.

MEISS LAKE FAULT

The Meiss Lake fault, previously unmapped, is a moderately well-defined, north-trending fault that offsets Holocene alluvium (Figure 2a). The fault exhibits geomorphic evidence suggesting a component of right-lateral strike-slip displacement in Plio-Pleistocene bedrock. The Meiss Lake fault is inferred to continue to the south through Meiss Lake and is delineated by tonal lineaments and an inferred east-facing scarp. The continuation of the fault south of Meiss Lake is delineated by a sharp tonal lineament in Holocene alluvium and a possible east-facing scarp (Figure 2a).

MT. HEBRON FAULT ZONE

The Mt. Hebron fault zone is a north to northwest-trending zone of normal faults up to 7 km wide (Figures 2a and 2b). Faults mapped by Wood (1960) juxtapose late Pleistocene alluvium against Holocene alluvium in Butte Creek drainage (Figure 2b) and offset Holocene alluvium at locality 27 (Figure 2a).

The fault mapped by Wood at locality 27 (Figure 2a) was not verified by this writer, based on air photo interpretation. Most of the traces of the Mt. Hebron fault are moderately to poorly defined and do not have geomorphic evidence of latest Pleistocene to Holocene displacement. However, there is evidence of late Quaternary displacement along this fault zone such as a possible scarp in a late Pleistocene(?) terrace at locality 30 (Figure 2b).

The easternmost fault in the Mt. Hebron fault zone south of Orr Mountain is moderately well-defined and is similar in geomorphic expression to faults of the Cedar Mtn. fault zone (Figure 2b). Although a Holocene alluvial fan is not offset, Butte Creek west of the fault has not re-established its gradient (locality 28, Figure 2b), indicating latest Pleistocene to Holocene displacement.

STEPHENS PASS FAULT

The Stephens Pass fault is a relatively short, north-trending normal fault with an unknown amount of cumulative down-to-the-east vertical displacement (Figure 2c). The fault had not been mapped prior to the August 1978 Stephens Pass earthquake swarm (Bennett and others, 1979). Although the largest event in this swarm was only M 4.6, surface fault rupture occurred for about 2 km along the fault and was expressed as fractures, scarps, and graben. These features clearly were associated with well-defined, pre-existing scarps, linear troughs, and graben, indicating that prior recent deformation due to surface fault rupture has occurred along the Stephens Pass fault (Figure 2c).

Several short, north to northeast-trending normal faults were mapped north of the Stephens Pass fault near Horse Peak (Figure 2c). These moderately to moderately well-defined faults are delineated by west and northwest-facing (uphill-facing) scarps in Quaternary volcanic bedrock. These faults lack geomorphic evidence of recent faulting similar to the Stephens Pass fault, such as troughs and/or fissures. This is based on air photo interpretation only, although these faults are located in an area of clear-cut timber harvesting and are much more visible than the Stephens Pass fault.

ASH CREEK FAULT ZONE

The Ash Creek fault zone is a north-trending zone of normal faults that offset Quaternary basalt (Figure 2c). Strands of the Ash Creek fault zone were mapped at a reconnaissance level by Gay and Aune (1959) (Figure 1) and are shown to offset alluvium near locality 34 (Figure 2c). The offset alluvium was not verified by this writer. The fault zone is only moderately defined and lacks geomorphic evidence of latest Pleistocene to Holocene offset (Figure 2c).

BLACK FOX MTN. FAULT ZONE

Strands of this previously unmapped, north-trending zone of normal faults are generally poorly defined and are not delineated by geomorphic features indicative of latest Pleistocene to Holocene offset (Figure 2c).

RECOMMENDATIONS

Recommendations for zoning faults for special studies are based on the criteria of "sufficiently active" and "well-defined" (Hart, 1988).

CEDAR MTN. FAULT ZONE

Zone for special studies well-defined traces of the Cedar Mtn. fault zone mapped by Wood (1960) and Bryant (this report) as depicted in Figures 2a and 2b (highlighted in yellow). Principal references cited should be Wood (1960) and Bryant (this report).

MAHOGANY MOUNTAIN FAULT ZONE

Zone for special studies well-defined traces of the Mahogany Mountain fault zone mapped by Wood (1960) and Bryant (this report) as depicted on Figure 2a (highlighted in yellow). Principal references cited should be Wood (1960) and Bryant (this report).

IKES MTN. FAULT

Do not zone traces of the Ikes Mtn. fault. This fault is neither sufficiently active nor well-defined.

MEISS LAKE FAULT

Zone for special studies well-defined traces of the Meiss Lake fault mapped by Bryant (this report) as depicted on Figure 2a (highlighted in yellow). Principal reference cited should be Bryant (this report).

MT. HEBRON FAULT ZONE

Zone for special studies the eastern trace of the Mt. Hebron fault zone mapped by Wood (1960) and Bryant (this report) as depicted on Figure 2b (highlighted in yellow). Principal references cited should be Wood (1960) and Bryant (this report).

Do not zone additional traces of the Mt. Hebron fault zone to the west. These faults are neither sufficiently active nor well-defined.

STEPHENS PASS FAULT

Zone for special studies well-defined traces of the Stephens Pass fault mapped by Bennett and others (1979) and Bryant (this report) as depicted in Figure 2c (highlighted in yellow). Principal references cited should be Bennett and others (1979) and Bryant (this report).

Do not zone the short northeast-trending faults located north of the Stephens Pass fault and south of Horse Peak. These faults are neither sufficiently active nor well-defined.

ASH CREEK FAULT ZONE

Do not zone traces of the Ash Creek fault zone. This fault zone is neither sufficiently active nor well-defined.

BLACK FOX MTN. FAULT ZONE

Do not zone traces of the Black Fox Mtn. fault zone. This fault zone is neither sufficiently active nor well-defined.

Report reviewed; recommendations approved. Earl W. Hart 5/9/90

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